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HELLFIRE
6-DOF Simulation Validation for Stockpile Reliability Program With Seeker Test Data

[redacted]

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13. ABSTRACT (MAXIMUM 200 WORDS)

The U.S. Army Test and Evaluation Command's Redstone Technical Test Center, in coordination with the U.S. Army Missile Command's Research, Development and Engineering Center, has continued in its concept of marrying Testing with Modeling & Simulation in order to improve the HELLFIRE Missile Stockpile Reliability Program testing and subsequent data interpretation. After years of component/subsystem lab bench testing, a six-degree-of-freedom (6-DOF) simulation which was developed during weapon system development is now being loaded with those tested parameters and operated in order to improve the acceptance decision. This report documents modifications to and the verification and validation of the 6-DOF simulation to accept the data resulting from this bench testing.

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PART I - INITIAL REVIEW
(Use Only for Unclassified Reports & Publications)

The attached information, HELLFIRE 6-DOF Simulation Validation for Stockpile Reliability Program with Seeker Test Data, has been reviewed in RTTC Electronic Component Test Branch by Kenneth G. LeSueur and determined to be factual and unclassified.

Kenneth G. LeSueur

04 Oct 94
DATE

PART II - OPSEC REVIEW
(Use Only for Unclassified Reports & Publications)

The attached information, HELLFIRE 6-DOF Simulation Validation for Stockpile Reliability Program with Seeker Test Data, has been given an OPSEC reviewed in the Redstone Technical Test Center by Carl E. Roberts and determined to be unclassified, nonsensitive, and suitable for public release.

Carl E. Roberts

5 Oct 94
DATE

PART III - PATENT APPLICABILITY REVIEW
(Use Only for Classified & Unclassified Reports & Publications)

The attached information, HELLFIRE 6-DOF Simulation Validation for Stockpile Reliability Program with Seeker Test Data, has been reviewed for patent applicability, in RTTC Electronic Component Test Branch by Kenneth G. LeSueur. The information

( ) appears to contain no patentable material.
( ) appears to contain patentable material.

( ) patent disclosure has been submitted.
( ) patent disclosure should be submitted.

Kenneth G. LeSueur

04 Oct 94
DATE

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The help of COLSA Corporation in the preparation of this document is gratefully acknowledged.

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1. Introduction

This report documents the results of efforts to use Stockpile Reliability Program (SRP) data with modeling and simulation in order to improve on HELLFIRE missile SRP testing and subsequent data interpretation. This will result in a better prediction of shelf life and thus reduce government costs.

After years of component/subsystem lab bench testing, a modified six-degree-of-freedom (6-DOF) simulation is now being loaded with those tested parameters and operated in order to improve the acceptance decision. The modified 6-DOF was originally designed for program development. Components/subsystems include the seekers, actuators, autopilots, batteries, and gyros. This report documents the modifications to and the verification and validation of the 6-DOF simulation in order to accept the data resulting from this bench testing.

This report also continues in the new direction taken by the marriage of Testing with Modeling and Simulation currently undertaken by the U.S. Army Test and Evaluation Command (TECOM) and Redstone Technical Test Center (RTTC) management. Close coordination between RTTC and the U.S. Army Research, Development and Engineering Center (RDEC)'s Guidance and Control (G&C) Directorate (and now RDEC's System Simulation Directorate) has enabled heading in this new direction [1].

The HELLFIRE SRP is managed by the Program Executive Office's (PEO) Air-to-Ground Missile Systems Project Management Office (PMO) and the U.S. Army Missile Command (MICOM) Product Assurance Directorate (PAD). It is executed by TECOM RTTC through bench tests of component/subsystems pulled from environmental storage locations for the SRP program and All-Up-Round (AUR) testing of sampled live stockpiled Laser HELLFIRE rounds for the Surveillance program.

The HELLFIRE SRP was designed to measure the performance of stockpiled missiles in order to project future stockpile performance, provide a basis for engineering and logistic corrective action, identify missile components/subsystems with marginal reliability, identify performance trends for corrective action, and assess missile shelf life through the identification of degradation trends. After performing HELLFIRE sample selection from environmental storage sites, missiles are shipped to RTTC for AUR testing, x-ray, disassembly, and component/subsystem functional testing. Statistics for the basic aged lot sample are used by the PMO for monitoring the stockpile. Some SRP missiles have been fired (flight tested), and rough impact data (miss distance) has been obtained. The data obtained in SRP testing has already been used in current efforts to extend the original 10-year shelf life of HELLFIRE and save the Army money.

Laser HELLFIRE simulations have always used design (new) parameters, including both deterministic and statistical values. This is due to the historical fact that simulation has been used strictly to help the research, development, and acquisition process, including developmental testing. Simulation has seldom, if ever, been used in the post-production process, or stockpile reliability/quality testing/predictions. In other words, this wealth of SRP data has up to now never been folded back into the simulation and used to analyze or predict the performance of aged HELLFIRE rounds. The SRP data could also be statistically analyzed to determine an aged-missile baseline (as compared to pre-production prototype data currently used in the 6-DOF for HELLFIRE development).

Simulation used with this data could in the future provide PAD with a better trend tool for augmenting the acceptance decision by providing better and more realistic prediction of expected performance. Ultimately, the work presented here will help PAD better formulate the answer to the question: When does degradation require pulling the missile from the field?

The work performed in gathering of data for SRP trend analysis, using this modified 6-DOF, will be used later to augment the surveillance van's HELLFIRE Missile Compact Test Set (HMCTS). This will be done by using the aged-missile data obtained for the SRP in conjunction with data gathered with the HMCTS. Together this data will be fed to the modified 6-DOF at the van for immediate simulation performance predictions of the tested missile.

2. Baseline Simulation

The baseline simulation used here is the 1987-dated HELLFIRE 6-DOF Laser Designator Weapon System Simulation (LDWSS) [2]. This 6-DOF was developed for HELLFIRE research and development and evolved by MICOM RDEC G&C from the 1977-dated Rockwell DIMODS simulation. It has been verified and validated against bench and test flight data for years. This simulation was obtained from G&C and implemented on a DEC Alpha 3000-300 machine, and on an IBM-compatible desktop PC computer.

Input to the 6-DOF consists of 3-card deterministic parameters (or biases) and 8-card one-sigma or statistical parameters. For instance, the initial pitch angle of the missile may be 4 degrees, give or take a degree or two. This fact will be modeled in the simulation as first a deterministic 3-card (or bias) of 4. Secondly, a random number is generated for the give or take variation. Two distributions are available for this random number: the Uniform distribution and the Normal distribution (or Bell curve). In the case of the initial pitch angle, testing has shown the variable/parameter follows a Normal distribution. Thus the random number generated for initial pitch angle is allowed to take values with a range of "give or take" of three standard deviations of say three degrees, and a one-sigma or one standard deviation of one degree. What this means is that, according to the Normal distribution, the chance of obtaining a variation of "give or take" one degree or less is 85%, of two degrees or less is 98%, and of three degrees or less is 99.9%. Thus the one-sigma 8-card was set to 1.0 in the 6-DOF.

A set of many runs, each leaving its launcher and impacting about the target, is required in order to determine performance using the above-described statistical simulation method. The first run might result in an initial pitch angle of 4.3 degrees, whereas the second run might result in 3.9, the third 3.8, the fourth 4.5, the fifth 4.2, and so on, in a random manner. This method is called Monte Carlo simulation due to the statistical roots in gambling.

Given correct inputs, the baseline simulation produces performance numbers and plots which are used in component/subsystem analyses. Performance numbers will be discussed later. A sample plot of altitude versus downrange for 100 runs in scenario "2A" (see Appendix E) is shown in Figure 1. This scenario is described in [3]. Analysis of simulation results were performed on individual run impact points and plots of pertinent variables, as well as multiple-run ensemble statistical performance figures consisting of Circular Error Probability or Probable (CEP) and Probability of Hit (P_h). The target used here is the old NATO standard target consisting simply of a 13 foot radius circle with an "X" painted at its center. In a set of impact points inside this target, CEP is defined as the radius of a circle such that half of all impact points fall within the prescribed circle. P_h is defined as the number of impacts inside the target boundary divided by the total number of impacts. Thus "Index-2" shown in the following figures is this P_h against the 13-ft radius NATO standard target.

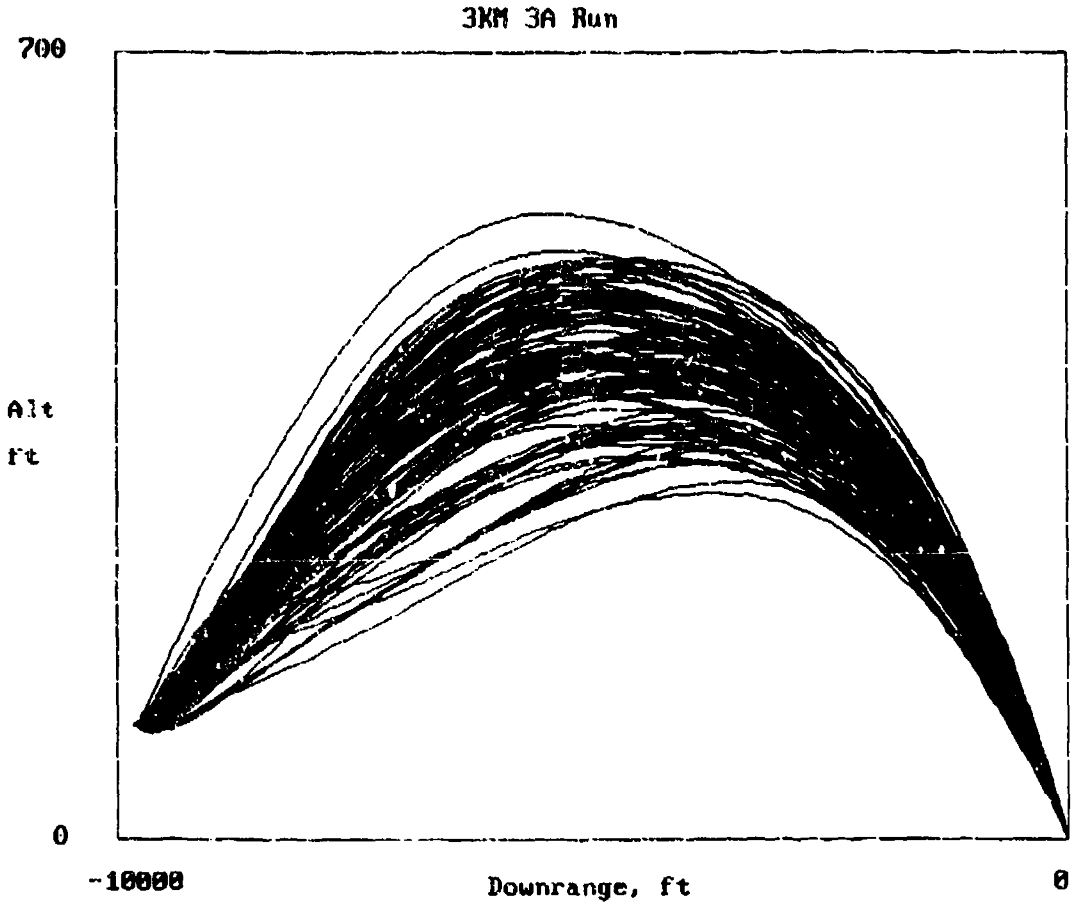


Figure 1. Sample 100-Run Altitude Versus Downrange 6-DOF Plot

3. Seeker Model Changes Required

Of interest to this seeker modeling and simulation group effort are 12 seeker parameters. See Table 1 for a list of these available variables as further described below. Other available component/subsystem parameters will be used in future studies/modifications.

In preparation, technical documentation residing at MICOM RDEC G&C (old HELLFIRE seeker files) was examined for seeker documentation [4 through 6]. This provided insight into the seeker model and the problems of different nomenclature and coordinate systems in the 6-DOF. In addition, it became obvious that the current HELLFIRE 6-DOF had to be modified.

Table 2 shows nominal parameters for 3-cards (biases, not 1-sigma noises) for the nominal values in the 6-DOF simulation corresponding to the above-mentioned measured parameters, their units, and the necessary conversion factors. Table 3 shows the input data HFUPDATE.DAT to the 6-DOF simulation containing relevant data for missile #600485. Table 4 shows the input data file containing data obtained from RTTC's seeker component/subsystem test database of 191 tests of 62 seekers during 5 years. There were some no-tests of failed seekers that were excluded from the database. Table 4 is significant because prior to this only pre-production seeker prototype data was available.

The seeker model was examined and adjusted. Refer to Table 5 for definitions of major variables changed. The current seeker model uses a single value of scale factor (GCSF) and internal noise (GNRMS or GNPTOP) common to both pitch and yaw. SRP data has a channel for each axis. It was necessary to modify the seeker model to enable use of test data and to maintain data fidelity. In addition, other associated code had to be cleaned up, corrected, or modified. The GNPTOP usage was discarded in favor of GNRMS throughout. Where the detector slope in yaw (STFY) was "wired" as a function of STFP (see code in Appendix A), it was made independent. Where the one-sigma for GNRMS was "wired" as a function of the bias, and with a fixed "tail" on the Normal distribution, it was made independent and made to read in the tail the normal way through 8-cards.

Subroutines S5I, NARPUL, and GYRO were modified. S5I is the main seeker initialization routine and contains the initialization for Monte Carlo and other seeker variables, and is called only once per run. On each integration pass, GYRO is called. GYRO models the spin torquer, gyroscopic effects, magnetic torques, and gimbal angle generation. NARPUL is called at the end of a pulse interval (if direct fire or after acquiring). NARPUL models the operation of the seeker detector and signal processor. It also selects the pulse to track, includes the effects of boresight shift, and generates the guidance command to the autopilot.

Where the old GNRMS and GCFS random variables were converted to GNRMSP and GCSFP, two new or additional random variables were implemented: GNRMSY and GSCFY. This required redefining a new baseline, since due to the two new random number generator calls per run, all Monte Carlo noises were skewed or changed for every run.

The channel split has been successfully accomplished. Code and data changes are enclosed as Appendices A and B.

Table 1. SRP Test Data Variables Used in Simulation

6-DOF C-array # & Variable Name[1]		RTTC Data-base Name	Used in which Model?	Avail-able Now?	Description of Variable
552	GNRMSP	P-Noise1	Seeker	Yes	Pitch Guidance Command Noise
1552	GNRMSY	Y-Noise1	Seeker	Yes	Yaw Guidance Command Noise
184	GCSFP	P-G-Cmd	Seeker	Yes	Pitch Guidance Command Scale Factor
2329	GCSFY	Y-G-Cmd	Seeker	Yes	Yaw Guidance Command Scale Factor
105	STFP	P-Slope	Seeker	Yes[2]	Pitch Guidance Command Transfer Function (slope)
106	STFY	Y-Slope	Seeker	Yes[2]	Yaw Guidance Command Transfer Function (slope)
531	ETHR	Trk-Sens	Seeker	Yes	Tracking Sensitivity
333	SFREQ	Freq1-50	Seeker	Yes	Gyro-Optics Spin Speed
578	GASFP	Pit-P10	Seeker	Yes	Pitch Gimbal Pot Scale Factor
579	GASFY	Yaw-P10	Seeker	Yes	Yaw Gimbal Pot Scale Factor
556	SZP1	P-Exc	Seeker	Yes[2]	Pitch Box Scan Excursion
559	SZY1	Y-Exc	Seeker	Yes[2]	Yaw Box Scan Excursion
860	TD2	Bw08del1	Autopilot[3]	Yes	LOAL High Time Delay
895	TD3	Bw08del2	Autopilot[3]	Yes	LOAL Low Time Delay
n/a	n/a	n/a	Actuators[3]	n/a	Sum of 4 Fin Pots at Zero Command
n/a	n/a	n/a	Actuators[3]	n/a	Sum of 4 Fin Pots at Full Hardover Command

1. New name (see Table 5).
2. For SRP bench component/subsystem test only (not available from AUR).
3. Data provided from AUR test using the HMCTS in van.

Table 2. Measured Parameters Versus Nominal 6-DOF Simulation Parameters

6-DOF C-array # & Variable Name		6-DOF Nominal Value[1] & Units	New RTTC Seeker Database 6-DOF Value	Conversion Factor	RTTC Database Name	RTTC "Nominal" Database Value[2] & Units
552	GNRMSP	0.092 volts RMS	0.1174	=	P-Noise1	0.1174 volts RMS
1552	GNRMSY	0.092 volts RMS	0.1146	=	Y-Noise1	0.1146 volts RMS
184	GCSFP	0.63256 volt-sec/deg	0.6046	=	P-G-Cmd	0.6046 volt-sec/deg
2329	GCSFY	0.63256 volt-sec/deg	0.6089	=	Y-G-Cmd	0.6089 volt-sec/deg
105	STFP	6.86 volt/deg	7.1344	=	P-Slope	7.1344 volt/deg
106	STFY	6.86 volt/deg	7.1484	=	Y-Slope	7.1484 volt/deg
531	ETHR	xxxxx[3] J/cm^2	xxxxx[3]	= see[3]	Trk-Sens	-1.834 dB off EMI spec
333	SFREQ	-439.6 rad/sec	-437.0	= -6.28*	Freq1-50	69.562 Hertz
578	GASFP	0.3 volt/deg	0.2892	= -0.833*	P gp sf	-3.4706 12*volt/deg
579	GASFY	0.3 volt/deg	0.2883	= -0.833*	Y gp sf	-3.4603 12*volt/deg
556	SZP1	0.6 volts	0.619	= *0.5*GASFP*	P-Exc	4.28 tot exc incl sf volts[4]
559	SZY1	4.8 volts	4.6513	= *0.5*GASFY*	Y-Exc	32.26 tot exc incl sf volts[4]
860	TD2	2.0 sec	2.0	=	Bw08del1	2.0 sec
895	TD3	4.15 sec	4.2	=	Bw08del2	4.2 sec

1. 3-card values
2. Nominal for component/subsystem (bench) tests
3. Classified # in this context
4. Not available for missile #600485 AUR test

Table 3. HFUPDATE.DAT File for Missile #600485 Run

Bias or 1-Sigma	Variable Name	Variable Number	Variable Value	Initialize Flag
3	Sample-3-card----	3515	0.123456789012	
8	Sample-8-card----	35150	0.123456789012	
3	RXE(KM) range	1615	-3.0	1.
3	RZE init alt ft	1623	-100.0	1.
3	OPTN4	3504	1.0	
3	OPTRJ	897	0.0	
3	NRUNS # runs	18	100.0	
3	----------------	1		
3	Msle 600485 data	1		
3	----------------	1		
3	GNRMSP	552	0.11	
3	GNRMSY	1552	0.12	
3	GCSFP	184	0.62	
3	GCSFY	2329	0.64	
3	STFP	105	6.86	
3	STFY	106	6.86	
3	ETHR	531	xxxxx[1]	
3	SFREQ	333	-433.0	
3	GASFP	578	0.3	
3	GASFY	579	0.3	
3	SZP1	556	0.6	
3	SZY1	559	4.8	
3	TD2	860	2.0	
3	TD3	895	4.15	
6				

1. In combination with the previous table, this number is classified.
2. Added zero signifies normally distributed variable.

Table 4. HFUPDATE.DAT File for Baseline Component/Subsystem Seeker Data

Bias or 1-Sigma	Variable Name	Variable Number	Variable Value	1-Sigma Left Extent	Initialize Flag	1-Sigma Right Extent	Time Series Sample Time
3	Sample-3-card----	3515	0.123456789012				
8	Sample-8-card----	35150	0.123456789012				
3	RXE(KM) range	1615	-3.0		1.		
3	RZE init alt ft	1623	-100.0		1.		
3	OPTN4 DIRECT FLT	3504	1.0				
3	OPTRJ DONTCARE	897	0.0				
3	NRUNS # runs	18	100.0				
3	----------------	1					
3	RTTC seeker data	1					
3	----------------	1					
3	GNRMSP seekrnoise	552	0.1174				
3	GNRMSY "	1552	0.1146				
8	GNRMSP timeSeries	5520	0.042	-3.		3.	.01
8	GNRMSY timeSeries	15520	0.0435	-3.		3.	.01
3	GCSFP scalefactr	184	0.6046				
3	GCSFY "	2329	0.6089				
8	GCSFP "	1840	0.1323	-3.		3.	
8	GCSFY "	23290	0.1199	-3.		3.	
3	STFP det slope	105	7.134				
3	STFY "	106	7.148				
8	STFP "	1050	0.953	-3.		3.	
8	STFY "	1060	0.952	-3.		3.	
3	ETHR track sensit	531	default used[1]				
8	ETHR "	5310	2.74E-16	-3.		3.	
3	SFREQ skrgyrofreq	333	-437.07				
8	SFREQ "	3330	3.7176	-3.		3.	
3	GASFP scalefactr	578	0.2892				
3	GASFY "	579	0.2883				
3	SZP1 boxscanexcur	556	0.619				
3	SZY1 "	559	4.651				
3	TD2 lowpitchdwn	860	2.0				
3	TD3 highpitchdwn	895	4.2				
6							

1. In combination with Table 2, this number is classified.
2. Added zero signifies normally distributed variable.

Table 5. Definitions of Major Variables Involved

Old Name	New Name	Description (P=Pitch, Y=Yaw)
AR	ARP ARY	Magnitude of seeker optical runout
ETHR	ETHR	Energy threshold density at seeker aperture
GASFP GASFY	GASFP GASFY	Seeker gimbal angle scale factor
GNFAC	GNFAC	Seeker nonlinear empirical gain for optical runout equation
GCSF	GCSFP GCSFY	Seeker guidance command scale factor
GNPTOP	(none)	Seeker guidance noise level in peak-to-peak volts
GNRMS	GNRMSP GNRMSY	Seeker guidance noise level in RMS volts (time series)
SFIXED	SFIXEP SFIXEY	Seeker guidance command scale factor at zero degree gimbal angle
SFREQ	SFREQ	Seeker gyro spin speed
STFP STFY	STFP STFY	Seeker detector linear region (about zero error) slope
SZP1 SZY1	SZP1 SZY1	Seeker box scan excursion mean
TD2	TD2	Autopilot's LOAL Low trajectory time to pitchdown
TD3	TD3	Autopilot's LOAL High trajectory time to pitchdown

4. Results for Verification and Validation

Eight multiple-run sets have been agreed to by RTTC and RDEC to be baseline run sets. The results of these eight standard baselined Monte Carlo run sets have been documented in memo form in [3] and will not be presented here. The verification/validation of the updated or modified simulation with the new code changes stated above was accomplished through comparison of the eight new versus old Monte Carlo run sets. Due to the resequencing of random number generation outputs induced by two more random number generator calls per run, large run sets were used to determine the baseline, and much shorter run sets were used to perform the studies. Results and comparisons are presented in Table 6, for the code and data changes presented in Appendices A and B.

The results shown in Table 6 show a very good comparison between old code and new code, especially for the 5,000-run cases 3A through 3D, as compared to the 100-run cases 2A through 2D. Greater precision with increased runs was expected. Although judgmental in nature, matches of less than one percent in performance statistics (in the 5,000-run cases) have to be called excellent by any evaluator.

In addition to statistical comparisons, individual run impacts and plots of interesting variables showed excellent comparison. The individual run impacts simply cannot be exhibited here due to their vast quantity. The plots differ so slightly that to the eye the resulting output plots produced by both old code and new code appear to be duplicates.

The 2A through 2D run sets or scenarios were used for the verification/validation and study evaluations. Figure 2 shows the comparison of the results of old code "baseline" versus the modified "new" code (with seeker data split into pitch and yaw). As in the discussion previously, it's a good match. This is a verification/validation of the modifications done, since with equivalent data, the old and new runs' curves line up atop each other. Equivalent data means the same values are used for both pitch and yaw channels in the modified code.

Figures 3 and 4 use the 2A run set or scenario only. They show the effect of GNRMS seeker noise bias value (3-card) and one-sigma value (8-card) on performance. It appears that the GNRMS seeker noise bias has little effect on performance, where its one-sigma value has significant effect. No table of values (to match the plots) are shown for sake of brevity.

Figures 5 and 6 also use the 2A run set or scenario only. They show the results of a study of GCSF scaling bias and of ATF detector slope on performance. Again, no table of values (to match the plots) are shown.

5. Comparisons

The results of Figures 3 through 6 were judged to be as expected by our experienced seeker testers. In addition, the same technical reports or memos that were used to provide some insight into the seeker model were also examined for comparability of performance results. Although interpretative and judgmental, the documentation seems to agree with the results presented here.

Table 6. Normalized Baseline Performance Numbers

Scenario or Case #	Baselined Simulation Normalized CEP & Index-2 Values	Simulation With New Modifications Normalized CEP & Index-2 Values	Change or Deviation Normalized CEP & Index-2's Percent Deviation[1]
2 A	0.90 & 1.00	0.93 & 1.00	+3.0 & +0.0 %
2 B	1.29 & 1.00	1.22 & 0.99	-4.8 & -0.1
2 C	1.26 & 1.00	1.25 & 1.00	-0.8 & +0.0
2 D	1.27 & 0.94	1.29 & 0.98	+1.8 & +4.2
3 A	1.00 & 1.0000	1.00 & 1.0000	+0.3 & +0.0 %
3 B	1.26 & 0.9974	1.27 & 0.9962	+0.2 & -0.1
3 C	1.25 & 0.9994	1.25 & 0.9994	+0.3 & +0.0
3 D	1.46 & 0.9682	1.32 & 0.9712	+0.7 & +0.3

1. Deviations determined prior to normalizing data.

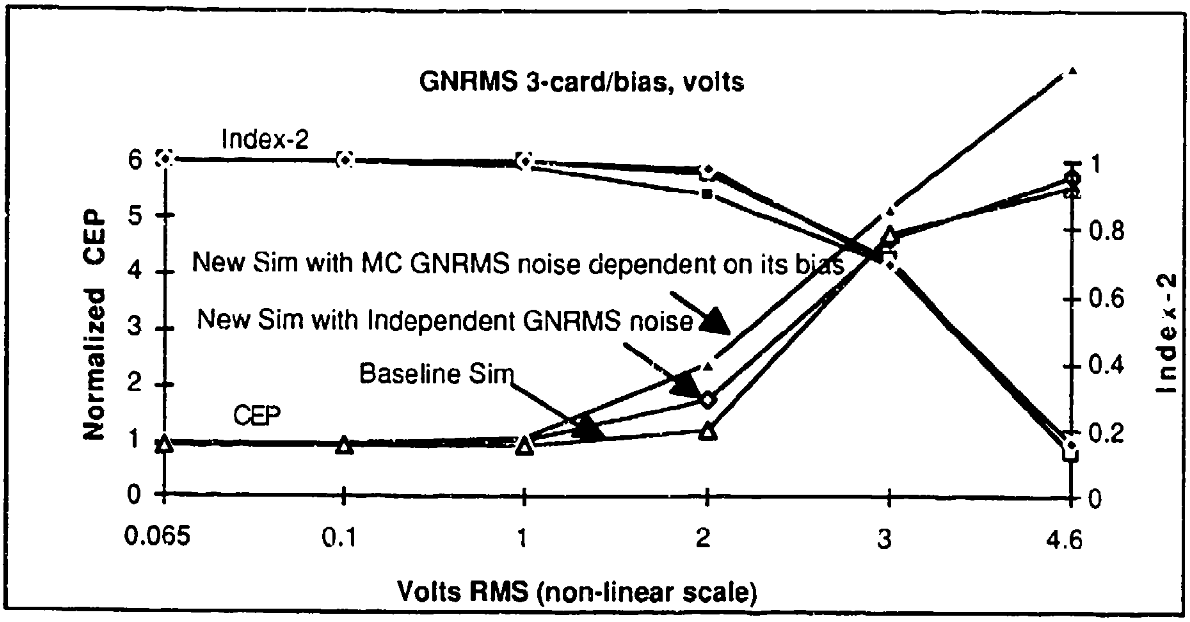


Figure 2. Validation of Guidance Command & Scale Factor Model Enhancements

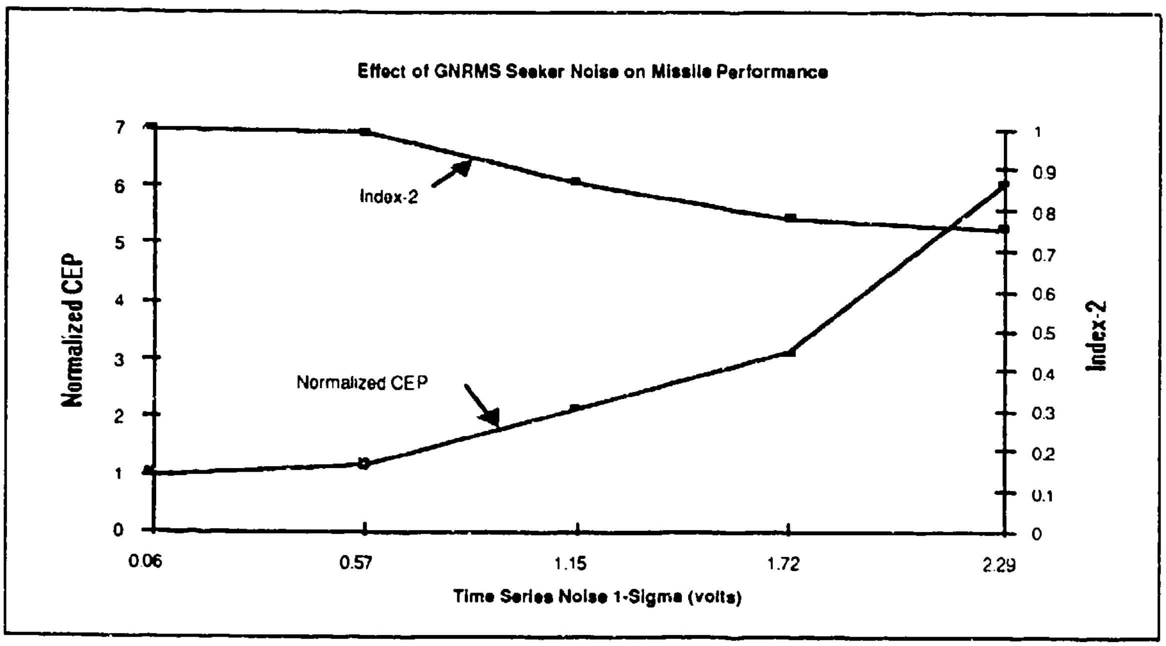


Figure 3. Effect of GNRMS Seeker Noise on Missile Performance

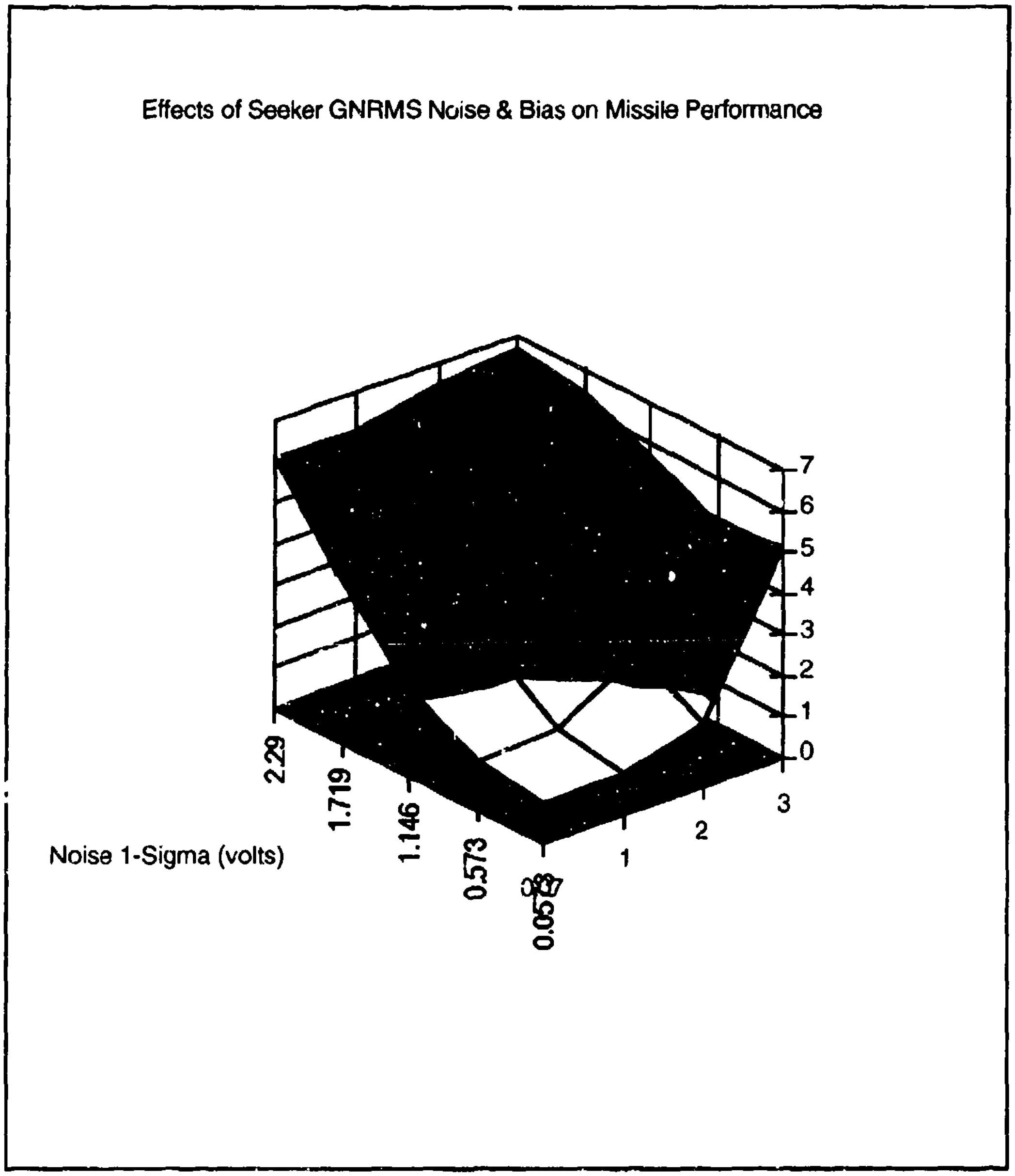


Figure 4. Effect of Seeker GNRMS Noise & Bias on Missile Performance

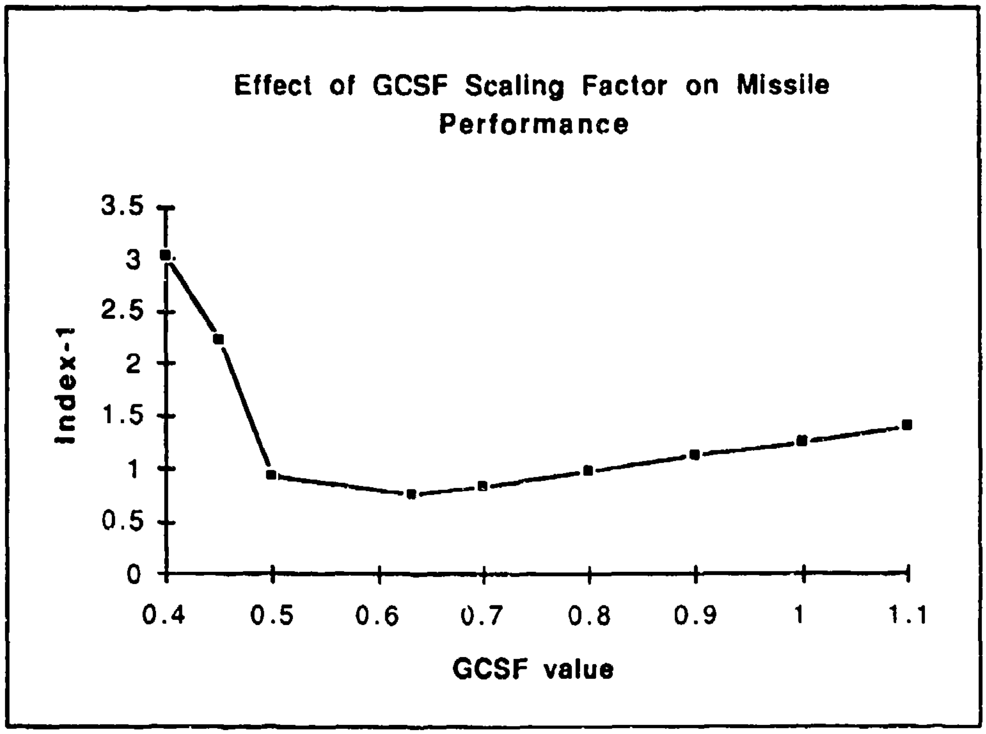


Figure 5. Effect of GCSF Scaling Factor on Missile Performance

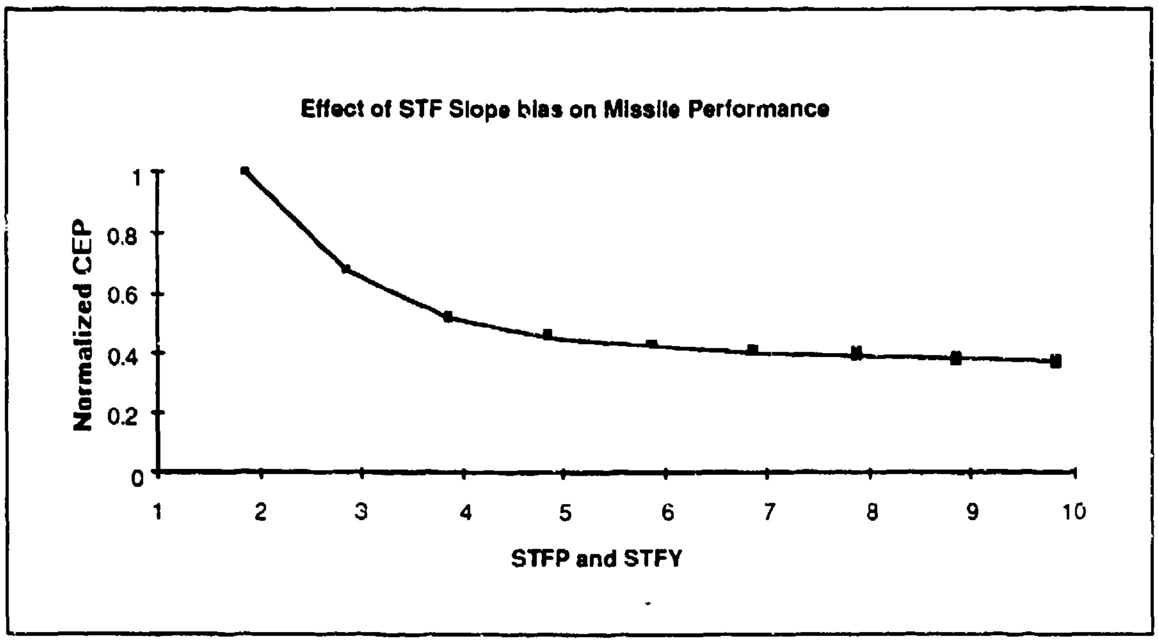


Figure 6. Effect of STF Slope Bias on Missile Performance

6. Performance Prediction for Missile #600485

In addition to the above verification/validation runs and other studies, data presented in Table 3 (pertaining to missile # 600485) was used for a 100-run set for case 2A. This resulted in a normalized CEP of 1.08 (normalized to the baseline 2A case), which was attributed to differences in the seeker parameters, and was expected.

The baseline data in the 6-DOF was taken from a hand-tooled seeker during the early HELLFIRE engineering development. Missile #600485's seeker is excellent but realistic. It is about two and a half dB better than current factory specification. As excellent as it is, it falls short of the preproduction prototype values' tracking sensitivity.

The 6-DOF modification allows reading in real missile component test data and predicting missile performance.

7. Performance Predictions with RTTC Seeker Component/Subsystem Database

Table 4 was used as the input to run a new baseline 6-DOF run with aged-missile data. This table contains the 3-card deterministic biases and 8-card statistical (one-sigma) data obtained from RTTC's seeker component/subsystem lab bench teardown tests. The database was used to obtain averages and standard deviations for several hundred seeker tests in 5 years' worth of tests.

Results of a case 3A 5,000-run set for this aged-missile seeker database show the normalized CEP to have increased to 1.84 for a 84% degradation, and the Index-2 normalized P_h decreased to 0.95 for a 5% degradation, which is somewhat expected. This information will define another baseline for further studies.

The above results are not part of the modification to or verification/validation of the 6-DOF, but rather a significant fact of aged-missile performance degradation for HELLFIRE stockpile missiles. This aged-missile performance study will be continued with actuator and autopilot data in another future report.

8. Conclusions/Expected Further Changes

The split of pitch and yaw channels in the seeker model was not a simple change. It did not require much new code or code changes, but it did require much research and analysis into the model in order to update the right code lines. It took time to gain some insight into the seeker model in order to produce a successful 6-DOF modification.

The modified HELLFIRE 6-DOF has been run with inputs from missile #600485 test data parameters, resulting in reasonable and expected performance for that one specific missile. This was done by using the test data values of Table 2 and preparing 3-cards for the Update input data file as shown in Table 3. A similar thing was done with the seeker component/subsystem lab bench test database, shown in Table 4, which produced somewhat expected results for aged missiles.

The modifications to the 6-DOF have been shown to produce similar and reasonable results for similar data, and results have been validated with bench test data.

The 6-DOF is ready for the next step, which is to modify its input routine to accept direct test data formats (without having to generate a set of 3-card and/or 8-card inputs per each missile, but rather one card of all missile parameters per run set).

Following that, executing the proper statistical run sets will develop (1) a new SRP baseline (data input to 6-DOF), for aged missiles which will include not only seeker but also actuators and autopilot, and (2) an acceptance criteria formed on SRP historical data to be used in aiding PAD with acceptance decisions. Along with repair records and possible flight test data, the SRP baseline would then be used to determine criteria for future real-time SRP test result decision making.

A potential application for the simulation tool exists to augment fielded assets surveillance testing at the AUR level through use of the HMCTS. Test results obtained via the test set would be evaluated for affects on predicted system performance.

The acceptance decision, based on the Normalized CEP system performance figures (such as that shown for missile #600485), must be made with PMO, RTTC and RDEC consensus after inputs or data are analyzed. Given that #600485 is an excellent missile, it still gave 8% degradation. But is a 50% increase in Normalized CEP acceptable? What about 100%? 150%? Where do we draw that line? HELLFIRE PMO inputs are needed due to the fact that this acceptance decision involves not only testing but also logistics and financial issues. For instance, firing two perhaps older missiles each with probability of hit of 70% will give the same probabilistic result as firing one missile with a P_h of 90%. Logistics and mission costs are higher for the two 70%'ers, but will there be any of those 90% missiles bought this year? In the battlefield weapons mix, will this matter? Is it necessary or even plausible that the HELLFIRE stockpile, now at its 10-year life specification, be replaced? Study of the SRP data already taken, soon to be put through the 6-DOF, might yield some important information upon which to make these decisions.

REFERENCES

1. Johnson (James), Holcomb and Alongi (Robert), "A Methodology for Assessing Impact of Subsystem Failures at the System Level for the HELLFIRE Missile," TECOM RTTC Technical Report TR-RD-TE-94-08, March 1994.

2. Alongi (Robert), Bosley and Lee, "LDWSS Users Guide," MICOM RDEC Guidance & Control Directorate Special Report RG-84-5, September 1984 (Unclassified).

3. Albanes, "Standard Run Sets for Laser HELLFIRE," controlled memo, 21 June 1994.

4. Bates (Harold), Farless, Gray and Lowman, "Preliminary HELLFIRE Laser Seeker Model Validation," MICOM RDEC Advanced Sensors Directorate Technical Report RE-CR-80-10, February 1980 (Confidential).

5. Rockwell International's HELLFIRE Modular Missile System proposal, T76-1400/03, circa 1976 (Secret).

6. Albanes working papers from various unrecalled reports from MICOM RDEC Advanced Sensors at G&C (Confidential).

7. Brantley, Hunt and Hawie, "HELLFIRE Stockpile Reliability Program Report: Electronic Component and Flight Tests," August 1994, MICOM RDEC PAD Internal Use Only report.

APPENDIX A

Comparing The Old Code and The New Code

---------- **Main Program C ıanges:**

```
*** The Old Code was
    PROGRAM HF6DOF

*** The New Code is
    PROGRAM HF6DOF
C
C   All-Up-Round code being implemented 6/94 by WVA
C     (split pitch and yaw for GCSF and GNRMS)
C   Used pairs of GCSF:184-2329, GNRMS:552-1552, SFIXE:567-2567,
C   AR:332-2332, and GNPFA:550-1550 (also had local variables)
C   Changes are in S5I, NARPUL and GYRO subroutines
*****
```

---------- **Subroutine Gyro Changes:**

```
*** The Old Code was
    EQUIVALENCE (C( 567),SFIXED)

*** The New Code is
    EQUIVALENCE (C( 567),SFIXEP)
    EQUIVALENCE (C(2567),SFIXEY)
*****


*** The Old Code was
    SF=SFIXED*FACTOR

*** The New Code is
C   Split for Pitch and Yaw  6/94 WVA
    SFP=SFIXEP*FACTOR
    SFY=SFIXEY*FACTOR
*****
```

*** The Old Code was

```
TYGDFT=SFIXED*A(18)*(GSENZ*AXS-GSENX*AZS)/CRAD
TZGDFT=SFIXED*A(18)*(GSENX*AYS-GSENY*AXS)/CRAD
```

*** The New Code is

```
C   Assume here that TY is Pitch and TZ is Yaw  6/94 WVA
    TYGDFT=SFIXEP*A(18)*(GSENZ*AXS-GSENX*AZS)/CRAD
    TZGDFT=SFIXEY*A(18)*(GSENX*AYS-GSENY*AXS)/CRAD
```

*****

*** The Old Code was

```
TORKB=SF*A(18)*(BRLIM-CCYTOP-STREPI+STREPC)/CRAD
TORKC=SF*A(18)*(CRLIM-CCPTOY-STREYI-STREYC)/CRAD
```

*** The New Code is

```
C  Split for Pitch and Yaw comes together here  6/94 WVA
C  Convention is B=Pitch, C=Yaw as per MICOM TR-RG-84-5 page 111
   TORKB=SFP*A(18)*(BRLIM-CCYTOP-STREPI+STREPC)/CRAD
   TORKC=SFY*A(18)*(CRLIM-CCPTOY-STREYI-STREYC)/CRAD
```

*****

---------- Subroutine NARPUL Changes:

*** The Old Code was

```
EQUIVALENCE (C( 332),AR)
```

*** The New Code is

```
EQUIVALENCE (C( 332),ARP)
EQUIVALENCE (C(2332),ARY)
```

*****

*** The Old Code was

```
ARRAD = AR/CRAD
ARGPH = PS*T + PHASE
ASINPH = ARRAD*SIN(ARGPH)
ACOSPH = ARRAD*COS(ARGPH)
```

*** The New Code is

```
C    Pitch and Yaw channels split 6/94 WVA
     ARPRAD = ARP/CRAD
     ARYRAD = ARY/CRAD
     ARGPH = PS*T + PHASE  !put it back
C    Splitting seeker noise into two channels begins...
C      Asinph=Pitch, Acosph=Yaw
     ASINPH = ARPRAD *SIN(ARGPH) !put it back
     ACOSPH = ARYRAD *COS(ARGPH)
```

*****

*** The Old Code was

```
ARAD=ARRAD/3.
 CALL NORM(RX,-3.0,3.0,0.0,ARAD)
 CALL NORM(RY,-3.0,3.0,0.0,ARAD)
```

*** The New Code is

```
C    ADD WHITE NOISE TO ASINPH AND ACOSPH        mod 6/94 wva
C This RX and RY are local variables, not spot or dynamics one
      CALL NORM(RX,GNLBP,GNUBP,0.,GNSPD/crad) !changes to rads
      CALL NORM(RY,GNLBY,GNUBY,0.,GNSYD/crad) !    "
      ASINPH=ASINPH+RX   ! This is all in rads
      ACOSPH=ACOSPH+RY
```

*****

```
*** The Old Code was
 145 EPSB(J) = EPSB(J) + ASINPH
     EPSC(J) = EPSC(J) + ACOSPH

*** The New Code is
C   Injecting Monte Carlo noise into seeker  6/94 WVA
C   B=Pitch, C=Yaw, and ASinph is Pitch, ACosph is Yaw, 6/94 WVA
 145 EPSB(J) = EPSB(J) + ASINPH !This may appear same but isn't
     EPSC(J) = EPSC(J) + ACOSPH !    "

*****
```

---------- **Subroutine S5I Changes:**

```
*** The Old Code was
     EQUIVALENCE (C( 184),GCSF)

*** The New Code is
     EQUIVALENCE (C( 184),GCSFP)
     EQUIVALENCE (C(2329),GCSFY)
*****

*** The Old Code was
     EQUIVALENCE (C( 332),AR)

*** The New Code is
     EQUIVALENCE (C( 332),ARP)
     EQUIVALENCE (C(2332),ARY)
*****
```

```
*** The Old Code was
    EQUIVALENCE (C( 550),GNPFAC)
    EQUIVALENCE (C( 552),GNPTOP)
    EQUIVALENCE (C( 552),GNRMS)

*** The New Code is
    EQUIVALENCE (C( 550),GNPFAP)
    EQUIVALENCE (C(1550),GNPFAY)
    EQUIVALENCE (C( 552),GNRMSP)
    EQUIVALENCE (C(1552),GNRMSY)
*****


*** The Old Code was
    EQUIVALENCE (C( 567),SFIXED)

*** The New Code is
    EQUIVALENCE (C( 567),SFIXEP)
    EQUIVALENCE (C(2567),SFIXEY)
*****


*** The Old Code was
    IF(ISNDX(I).EQ.105)STFY=SA1*STFP+SA2
    IF(ISNDX(I).EQ.106)CALL MCARLO(-2, IDO)

*** The New Code is
C ** TOOK OUT THE IF(ISNDX(I).EQ.105)STFY=SA1*STFP+SA2 FOR P/Y
    IF(ISNDX(I).EQ.106)CALL MCARLO (1, IDO) !Had a -2 7/94 wva
*****


*** The Old Code was
C**GUIDANCE COMMAND SCALE FACTOR
    IF(ISNDX(I).EQ.184)CALL MCARLO (1, IDO)
```

*** The New Code is

```
C GUIDANCE COMMAND SCALE FACTOR (Pitch and yaw split 6/94 WVA)
      IF(ISNDX(I).EQ.184)CALL MCARLO (1, IDO)
      IF(ISNDX(I).EQ.2329)CALL MCARLO (1, IDO)
```

*****

*** The Old Code was

```
C**GUIDANCE NOISE
      IF(ISNDX(I).EQ.552)CALL MCARLO (1, IDO)
```

*** The New Code is

```
C**GUIDANCE NOISE (Now pitch and yaw split 6/94 WVA)
      IF(ISNDX(I).EQ.552)CALL MCARLO (1, IDO)
      IF(ISNDX(I).EQ.1552)CALL MCARLO (1, IDO)
```

*****

*** The Old Code was

```
      SFIXED=1./GCSF
```

*** The New Code is

```
      SFIXEP=1./GCSFP
      SFIXEY=1./GCSFY
```

*****

*** The Old Code was

```
      GNFAC=1.088
      AR=GNFAC*GNRMS*(1./STFP-.025*SFIXED)
```

*** The New Code is

```
C This nonlinear GNFAC number is for (GN)RMS value of noise level
C   It was 0.5 for (GNPTOP) peak value of noise level
      GNFAC=1.088
      ARP=GNFAC*GNRMSP*(1./STFP-.025*SFIXEP)
      ARY=GNFAC*GNRMSY*(1./STFY-.025*SFIXEY)
C   Conversion of 8-card noise 1-sigmas from volts to DEGREES
      GNSPD=GNFAC*GNSIGP*(1./STFP-.025*SFIXEP)
      GNSYD=GNFAC*GNSIGY*(1./STFY-.025*SFIXEY)
C
C   ARP, ARY, GNSPD and GNSYD are in DEGREES rather than volts
C
```

*****

*** The Old Code was

```
      GNPFAC=1./(1./STFP-.025*SFIXED)*57.29578
```

*** The New Code is

```
      GNPFAP=1./(1./STFP-.025*SFIXEP)*57.29578 !57.3 means rads
      GNPFAY=1./(1./STFY-.025*SFIXEY)*57.29578 !     "
```

**

*** The Old Code was

```
      IF(ITNDX(I).NE.552)GO TO 511
```

*** The New Code is

```
C    Now pitch or yaw channels   6/94 WVA
      IF(ITNDX(I).EQ.552)IMC1=I
      IF(ITNDX(I).EQ.1552)IMC1=I
```

*****

APPENDIX B

Comparing Old Data File and New Data File
(compressed 8-cards for presentation)

*** The Old Data File was:

3 STFP	105	6.86
3 STFY	106	7.0045

*** The New Data File is:

3 STFP	105	6.86
3 STFY	106	6.86

*****

*** The Old Data File was

3 GCSF	184	.63258

*** The New Data File is

3 GCSFP	184	.63258
3 GCSFY	2329	.63258

*****

*** The Old Data File was

3 GNRMS	552	.092

*** The New Data File is

3 GNRMSP	552	.065
3 GNRMSY	1552	.065

*****

*** The Old Data File was:

8 STFP	1050	.525	-3.	3.
8 STFY	1060	.525	-2.866	3.134

*** The New Data File is:

8 STFP	1050	.525	-3.	3.
8 STFY	1060	.525	-3.	3.

*****

*** The Old Data File was

```
8 GCSF          1841    1.    -.02511  .02511
```

*** The New Data File is

```
8 GCSFP         1841    1.    -.02511  .02511
8 GCSFY         23291   1.    -.02511  .02511
```

*****

*** The Old Data File was

```
8 GNRMS TimeSeries  5520   .3333  -3.   3.   552 .01
```

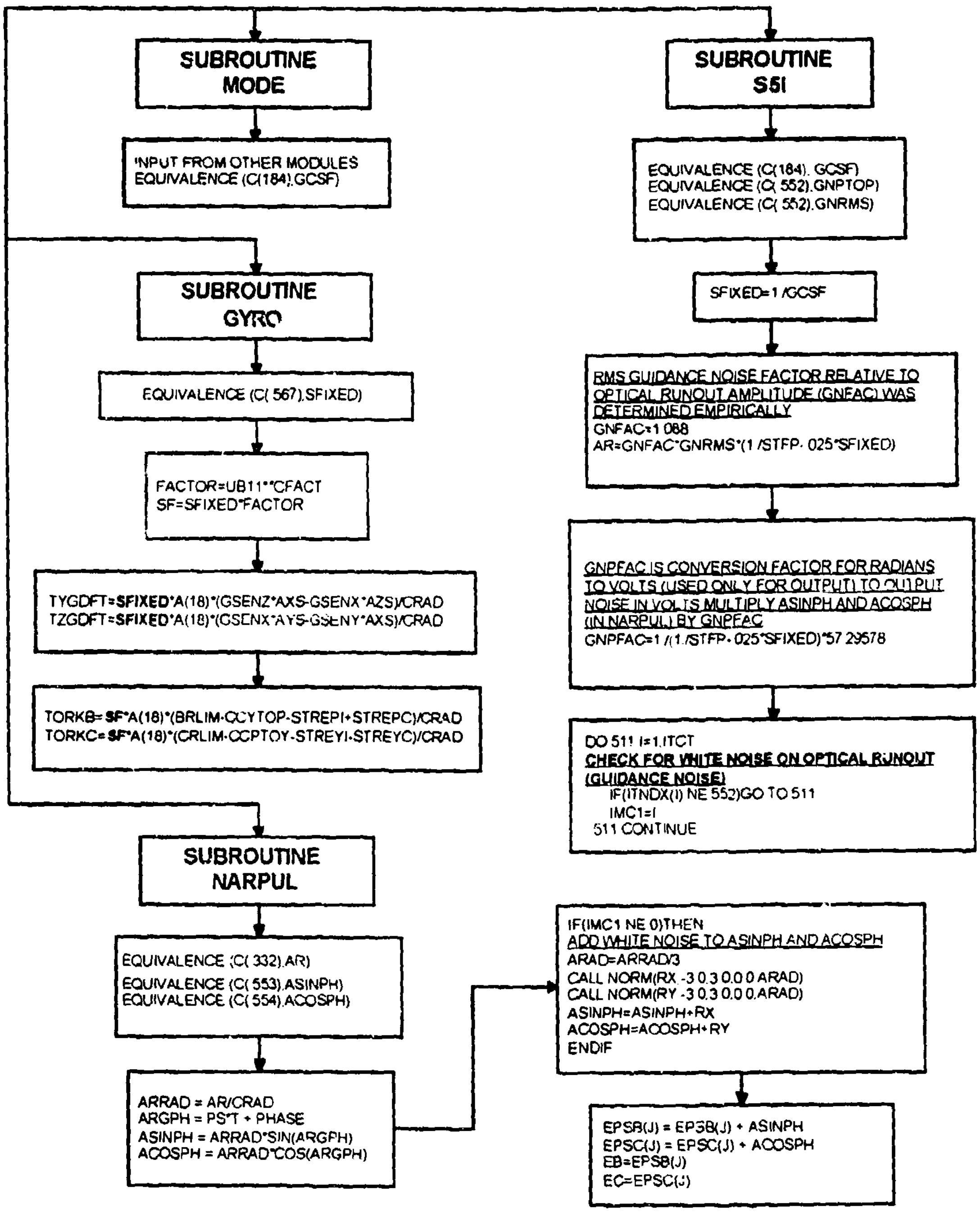
*** The New Data File is

```
8 GNRMSP TimeSers   5520   .236   -3.   3.   552 .01
8 GNRMSY TimeSers   15520  .236   -3.   3.   1552 .01
```

APPENDIX C

Supporting Calculations for Guidance Command Scale Factor (GCSF) and Guidance Noise (GNRMS) Before Changes

Supporting Calculations for Guidance Command Scale Factor (GCSF) and Guidance Noise (GNRMS) before changes



APPENDIX D

Supporting Calculations for Guidance Command Scale Factor (GCSF) and Guidance Noise (GNRMS) with Changes

Supporting Calculations for Guidance Command Scale Factor (GCSF) and Guidance Noise (GNRMS) with changes

SUBROUTINE GYRO

```
EQUIVALENCE (C( 567),SFIXEP)
EQUIVALENCE (C(2567),SFIXEY)
```

```
FACTOR=UB11**CFACT
SFP=SFIXEP*FACTOR
SFY=SFIXEY*FACTOR
```

```
TYGDFT=SFIXEP*A(18)*(GSENZ*AXS-GSENX*AZS)/CRAD
TZGDFT=SFIXEY*A(18)*(GSENX*AYS-GSENY*AXS)/CRAD
```

```
TORKB=SFP*A(18)*(BRLIM-CCYTOP-STREPI+STREPC)/CRAD
TORKC=SFY*A(18)*(CRLIM-CCPTOY-STREYI-STREYC)/CRAD
```

SUBROUTINE NARPUL

```
EQUIVALENCE (C( 332),ARP)
EQUIVALENCE (C(2332),ARY)
```

```
ARPRAD = ARP/CRAD
ARYRAD = ARY/CRAD
ARGPH = PS*T + PHASE
ASINPH = ARPRAD *SIN(ARGPH)
ACOSPH = ARYRAD *COS(ARGPH)
```

ADD WHITE NOISE TO ASINPH AND ACOSPH

```
CALL
NORM(RX,GNLBP,GNUBP,0 ,GNSPD/crad)
NORM(RY,GNLBY,GNUBY,0 ,GNSYD/crad)
ASINPH=ASINPH+RX
ACOSPH=ACOSPH+RY
```

Injecting Monte Carlo noise into seeker
B and ASINPH = Pitch, C and ACOSPH = Yaw

```
EPSB(J) = EPSB(J) + ASINPH
EPSC(J) = EPSC(J) + ACOSPH
```

SUBROUTINE S5I

```
EQUIVALENCE (C( 184),GCSFP)
EQUIVALENCE (C(2329),GCSFY)
EQUIVALENCE (C( 332),ARP)
EQUIVALENCE (C(2332),ARY)
EQUIVALENCE (C( 550),GNPFAP)
EQUIVALENCE (C(1550),GNPFAY)
EQUIVALENCE (C( 552),GNRMSP)
EQUIVALENCE (C(1552),GNRMSY)
EQUIVALENCE (C( 567),SFIXEP)
EQUIVALENCE (C(2567),SFIXEY)
```

```
IF (ISNDX(I) EQ 106)CALL MCARLO (1,IDO)
```

```
IF(ISNDX(I) EQ 184)CALL MCARLO (1, IDO)
IF(ISNDX(I) EQ 2329)CALL MCARLO (1, IDO)
IF(ISNDX(I) EQ 552)CALL MCARLO (1, IDO)
IF(ISNDX(I) EQ 1552)CALL MCARLO (1, IDO)
```

```
SFIXEP=1 /GCSFP
SFIXEY=1 /GCSFY
```

RMS GUIDANCE NOISE FACTOR RELATIVE TO OPTICAL RUNOUT AMPLITUDE (GNFAC) WAS DETERMINED EMPIRICALLY

```
GNFAC=1 088
ARP=GNFAC*GNRMSP*(1 /STFP- 025*SFIXEP)
ARY=GNFAC*GNRMSY*(1 /STFY- 025*SFIXEY)
```

Conversion of S-card noise 1-sigmas from volts to Degrees

```
GNSPD=GNFAC*GNSIGP*(1 /STFP- 025*SFIXEP)
GNSYD=GNFAC*GNSIGY*(1 /STFY- 025*SFIXEY)
```

GNPFAC IS CONVERSION FACTOR FOR RADIANS TO VOLTS (USED ONLY FOR OUTPUT) TO OUTPUT NOISE IN VOLTS MULTIPLY ASINPH AND ACOSPH IN NARPUL) BY GNPFAC

```
GNPFAP=1 /(1 /STFP- 025*SFIXEP)*57 29578
GNPFAY=1 /(1 /STFY- 025*SFIXEY)*57 29578
```

CHECK FOR WHITE NOISE ON OPTICAL RUNOUT (GUIDANCE NOISE)

```
IF (ITNDX(I) EQ 552) IMC1=I
IF (ITNDX(I) EQ 1552) IMC= I
```

SUBROUTINE MODE

```
EQUIVALENCE (C( 184),GCSFP)
EQUIVALENCE (C(2329),GCSFY)
```

APPENDIX E

Standard Run Sets for Laser HELLFIRE

6/21/94 Willy Albanes

STANDARD RUN SETS FOR LASER HELLFIRE

RTTC has a need to agree to a "standard run set" for running HELLFIRE studies. This is necessary for all-up-round performance and for all submodel performance studies.

We have to be careful here because the agreement with Bob Alongi at MICOM RDEC G&C is that RTTC does not present absolute performance figures for HELLFIRE unless it is done through Alongi or his representative (me).

The absolute performance prediction of a HELLFIRE missile using simulation has been shown in a study ran last Summer to be 90% confident only if several thousand runs per set are executed. We have settled on a 5,000-run set for absolute performance.

Seems to me that the "standard run set" for comparison of two submodels, rather than for absolute performance, should take considerably less number of runs. The suggestions that follow assume a working configuration control of code and data files (3-card and 8-card both). Therefore I suggest the following:

1. Standard for each of the following sets is:
    a. Target stationery ... just sitting there.
    b. Target sitting at zero height to ground.
    c. Target has no geometry ... just a 13-ft sphere for Ph calculations.
    d. Initial missile altitude to ground is 100 feet.
    e. Initial missile velocity zero.
    f. Initial missile pitch angle (Qe) is 4 degrees up from horizontal.
    g. TADS designator at 3km range (we do not want to study the designator here).
    h. Standard seeker, autopilot and actuator parameters as per 1984 TR and standard 3-card and 8-card data files dated 1987.

2. Four run sets are suggested (again, for quick comparison):
    a. A 100-run set of 3 km direct (LOBL), target in-line.
    b. A 100-run set of 5 km LOAL Low, target in line.
    c. A 100-run set of 5 km LOAL High, target in line.
    d. A 100-run set of 5 km LOAL Low with target 15 degrees initial yaw offset.

3. For a more detailed comparison and baseline, when we can afford the computer resources and wall clock time required, then the suggestion is to run the same four run sets detailed above, except for 5,000-run sets rather than 100-run sets.

Again, keep in mind that what is proposed here is a baseline. If you want to study the effects of designator range on seeker performance and thus missile performance, go ahead ... just compare your study results to the above baseline's results.

The results of the above suggested baseline (CEP and Ph) cannot be shown here due to classification ... refer to me in person.

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